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THE QUESTION OF MODELING CERTAIN MOTOR FUNCTIONS OF THE HUMAN ARM

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ABSTRACT. The modeling of the motor functions of the human arm by master-slave manipulators is discussed. The use of the lateral-pulse method to modulate the control signal is presented.

There are a number of different designs of manipulators in use today in a number of branches of science and engineering, but even the most modern of them lag well behind the capabilities of the human arm. /161

It is becoming evident that further improvement of manipulators can be quite successful provided careful study is made of the mechanism in the human body that controls arm movements, that the features of the control laws are exposed, and that they are modeled on the basis of the latest achievements of scientific and technical thought.

The human arm differs from a mechanism by having active, as well as kinematic, muscular ties. And the number of active muscular ties involved in some displacement usually is more than one. It should be emphasized that the muscular ties of the human arm, as distinguished from a mechanism, are active.

The bones of the skeleton of the human arm are surrounded by several layers of muscles that perform the variety of functions involved in movement. Two types of muscle interactions have come to be accepted: synergism, and antagonism. The former involves the performance of common work, the participation of the muscles in the same movement. In the case of antagonism the different groups of muscles participate in opposite movements. The central nervous system, by most precise metering of the forces of muscle-antagonists, regulates the speed of the movement, and the force, brakes the movement, and provides smoothness from the beginning to the end of the movement.

A drive using two motors can be built to serve as the analog of the muscles of the synergists and antagonists.

Control of the "antagonist" and "synergist" motors for example by changing the supply voltage will result in realization of a similar work mode.

The characteristics of the speed with which the human arm acts are distinguished by an extremely great range. Yet along with rapid movements of great power the human arm performs the most complicated and most precise operations with minimum effort. These potentials can be reached primarily because a muscle making whatever movement consists of fast and slow fibers which are grouped into different neuromotor units and are controlled by the central nervous system according to the task assigned.

The command to begin the movement, its speed, the force with which the /162
muscles are to contract, yields a train of impulses that flows along the nerve fibers from the central nervous system to the muscles. The nerve impulse repetition frequency determines the degree to which the muscle is excited.

The power of the contractile act on the part of the muscles of the human arm is determined by the nerve impulse repetition frequency, as well as by nerve impulse amplitude. The following table is from Yu. M. Uflyand [1].

TABLE

Nature of Contraction	Pulse Amplitude	Pulse Frequency
Tonic activity	50-100 μV	-
Involuntary contraction	200-400 μV	50-70 pps
Strong contraction	1500-2000 μV	200 pps

High-powered master-slave manipulators most often are built on the hydraulic drive principle. As we know, the initiation of the movement of a hydraulic drive is usually accompanied by some kicking, or jerking, the cause of which is the static friction that alwways is present with dry friction. It occurs in the packing glands of the moving part of the drive because of packing compression.

This naturally makes it difficult to use manipulators for operations requiring increased accuracy and precision.

The most rational way to eliminate the effect of static and dry friction from the control process is vibration linearization of the drive. Analogous to it, in essence, is the so-called tonic activity of man's skeletal muscles.

Muscle tonus is associated with the supply to the muscle of a train of nerve impulses with a minimum rest frequency exciting different muscle fibers alternately. Thus, the entire system is in a dynamic state with a high reaction rate to external stimulation. The inertia of the members of the body damp the rest oscillations in the rest state, thus preventing them from increasing in amplitude.

Similar control modes are widely used in modern engineering.

The essence of the operation of these systems involves setting up a vibration mode of operation of the distributors. But this mode can be limited to any element in the follow-up drive, to and including the slave motor, depending on the pulse repetition frequency.

The advantages in having the system operate in vibration modes are the high rate of speed and sensitivity of the system, the high reliability, elimination of the influence of change in temperature, cleanliness of the working fluid, reduction to a minimum of the influence of static and dry friction in system elements, and zero hysteresis and drift in amplifier circuits.

Practice in the building and operation of remotely controlled manipulators with electrohydraulic control systems has shown that high levels of static and dry friction in the slave drive will reduce sensitivity and precision and will cause kicking during starting. Contrl by lateral-pulse modulation gives the desired characteristics, thus increasing the efficiency of the manipulators.

Special selection of the frequency for vibration linearization of the control system can result in an operating mode similar to the tonic activity of the skeletal muscles of the human arm in the rest state. /163

The P. P. Shirshov Institute of Oceanology of the Academy of Sciences of the USSR has, in recent years, been engaged in research on the use and improvement of electrohydraulic control systems for underwater master-slave manipulators operating in the lateral-pulse modulation mode.

The error signal in these systems is the difference in the voltages across the position sensors for the command and slave elements. This difference voltage is converted by a transistor amplifier performing like a Class D amplifier into a pulse train changing differentially with respect to width. The converted

signal acts on the relay of a nozzle-slide type hydraulic amplifier that controls the movement of the distribution slide-valve. Displacement of the latter moves the piston in the slave cylinder.

The slide in the hydraulic amplifier oscillates at zero input signal, and the mean speed of the slide-valve for the period is zero. In the unbalanced input signal case the slide of the hydraulic amplifier spends more time at one nozzle than at the other during each switching cycle. Now the mean speed is not zero.

A symmetrical semiconductor triode multivibrator (Figure 1) is used as the source of periodic rectangular pulses that convert the continuous input signal into a train of temporarily modulated pulses.

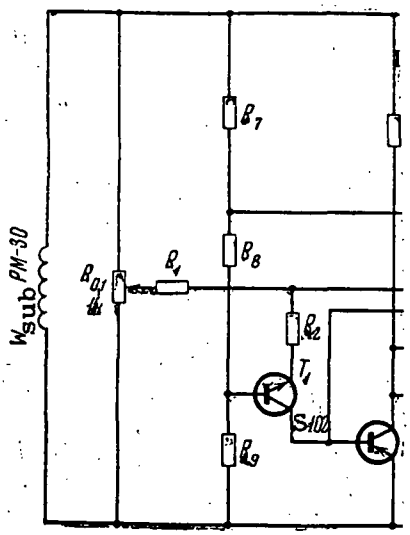

Figure 1. Principal schematic of the pulse amplifier.

The transistors have low internal resistance when conducting in the pulse mode, high efficiency, and stable temperature variation and operating voltage curves. Temperature stabilization of the working point is not required because transistor cutoff and saturation regions are easily provided by trigger pulses greater in magnitude than the current and voltage values occurring with change in temperature [2].

Transistors need not be selected in terms of parameters when semiconductor amplifiers operating in the pulse mode are used. It is sufficient to satisfy to condition $\beta \geq \beta_{min}$, where β is transistor current gain factor in a circuit

with a common emitter.

Some voltage $U_{be} \geq -0.3$ to -0.5 V must be applied between the bases and emitters of the transistors in the input stage in the balanced position in order to reduce to a minimum the zones of amplifier insensitivity. This can be done by inserting a voltage divider between bases and emitters of the transistors in the input stage. In this case the magnitude of the threshold voltage, U_{be}, is determined by the voltage drop across R_8.

The oscillograms in Figure 2 illustrate the advantages noted for a manipulator control system using lateral-pulse modulation of the control signal.

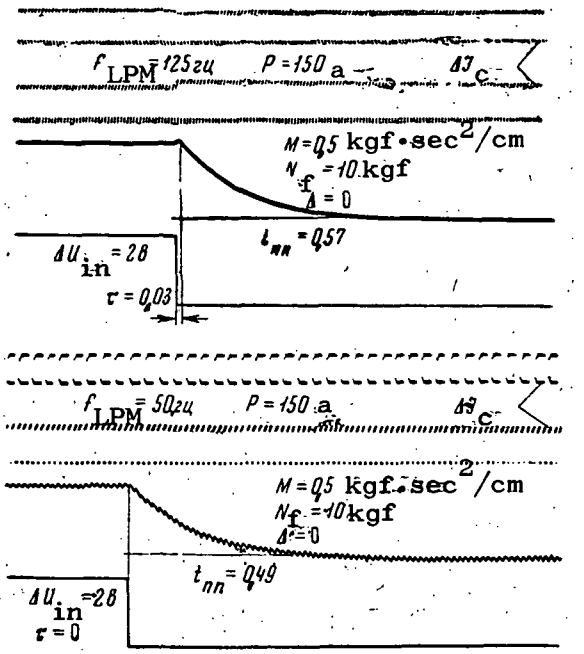

Figure 2. Oscillograms of transients in a manipulator control system using lateral-pulse modulation of the control signal.

The control signal, $U_{in} = 2$, is supplied to the input of the electro-hydraulic system for controlling the manipulator in the form of a function changing stepwise. The pressure of the working fluid at the input to the hydraulic distribution was 150 kgf/cm^2.

Oscillograms were recorded when the frequency of the linearizing oscillations was 50 and 125 Hz. In the first case oscillations of the slave motor ram with amplitudes to 0.1 mm were observed. In the second case the amplitude of the oscillation of the slave motor ram were so small (less than the turn sensitivity of the feedback potentiometer) it was barely perceptible, even to the touch. The net delay in the first case is practically zero, in the second 0.03 sec. There is no static error in the system in either case when friction is increased to 10 kgf. /165

Recapping, we can formulate the following conclusions:

1. The characteristics of master-slave manipulators can be improved by studying the mechanism that controls the human arm and by rational modeling of these functions.

2. The characteristics of master-slave manipulator control systems can be improved substantially by using the lateral-pulse method to modulate the control signal.

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